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Response of Migrating Adult Salmonids to Vertical and Horizontal Rectangular Orifices at Two Depths*

by Clark S. Thompson, William Spencer Davis, and Emil Slatick

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* This is to distinguish between Oriental and American Salmon.

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By

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ABSTRACT

The response of migrating adult salmonids to various placements of rectangular fishway orifices was studied at the Fisheries-Engineering Research Laboratory, on the Washington end of Bonneville Dam. Chinook salmon (Oncorhynchus tshawytscha), steelhead trout (Salmo gairdneri), and coho salmon (O. kisutch) approaching a vertical wall had the alternatives of entering rectangular orifices positioned either horizontally or vertically and either shallow (3 feet) or deep (9 feet). The responses of the three species to the various orifice conditions are analyzed. More migrants passed through shallow orifices than deep orifices, and more salmonids entered vertical orifices than horizontal orifices.

INTRODUCTION

The position and type of entrance used to attract migrating fish into fishways can be important factors in expediting the movement of fish at dams. A key part of fish-facility complexes at most hydro-electric plants on the Columbia River is the powerhouse fish-collection system, a long channel extending across the face of the powerhouse and containing a number of entrances for fish. This channel is one of several routes to the main fishways. To enter the powerhouse collection channel, however, migrants attracted by the turbine discharge must locate entrance ports above the turbine draft tubes. Large discharges from fishway entrances also attract numerous migrants directly to the entrances of the main fish ladders.

Fish-collection systems have been studied by the Corps of Engineers to determine the design criteria that would provide optimum entry conditions for upstream migrants. Experiments at Bonneville Dam indicated that salmonids will enter the powerhouse collection system more readily through a submerged orifice than over an overfall weir entrance (U.S. Corps of Engineers, 1948). Studies in 1952 and 1954 (U.S. Corps of Engineers, 1960b) showed that shallow orifices (those submerged 3.8 to 6 feet) were more effective as entrances for fish than intermediate (14.8 feet) or deep orifices (30 feet). Continued research in 1960 indicated that more fish used vertical orifices than horizontal orifices (U.S. Corps of Engineers, 1960a), but results were not conclusive.

The purpose of this study was to compare the response of adult salmonids to rectangular orifices placed in a vertical wall and aligned vertically or horizontally, at shallow or deep settings. The work was done in the Fisheries-Engineering Research Laboratory[1] at Bonneville Dam from August 24 to September 20, 1962.

MATERIALS AND METHODS

Test facilities (fig. 1) were housed in the laboratory where special orifices and fishways could be operated under controlled hydraulic conditions. Test fish entered the laboratory from the Washington shore fishway, passed through experimental orifices and associated transportation channels, and returned to the main fishway on their own

[1] Research financed by the U.S. Army Corps of Engineers as part of a broad program to provide design criteria for more economical and efficient fish-passage facilities at Corps' projects on the Columbia River.

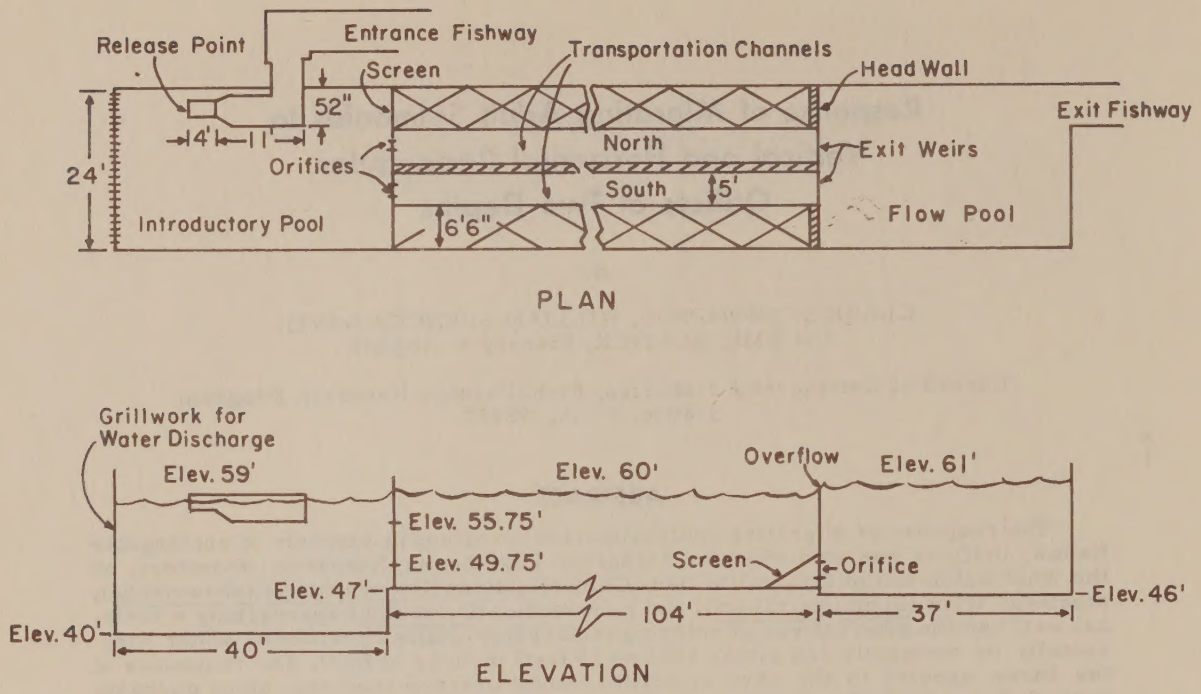


Figure 1.--Plan and elevation views of laboratory, showing release point, location of orifices, and exit weirs where fish passage was recorded. Sectional view shows water elevations and centerline of orifices.

volition. Responses of adult salmonids to the various orifice locations were determined by counting the fish as they left individual transportation channels upstream from the orifices.

Laboratory

Collins and Elling described the laboratory in detail (Collins and Elling, 1960). A water supply and discharge system capable of delivering and discharging up to 200 cubic feet per second (c.f.s.) provided water for the experimental area. Flows were regulated by various intake valves and a large drain valve.

A battery of 1,000-watt mercury-vapor lights spaced at 6-foot intervals, 6 feet above the water, produced an average light intensity of 700 foot-candles at the water surface. This light was similar to natural light measured in the main Bonneville fishway during a bright cloudy day.

Orifices.--Orifices used in this study were 2- by 5-foot rectangular ports installed at the junction of the introductory pool and the two transportation channels (fig. 2). The orifice panels fitted into guides and could be removed (fig. 3), turned 90°, and replaced to change the orifice setting from vertical to horizontal (fig. 4) or vice versa. Solid panels filled the space above and below the orifice panels.

The centerline of the orifice was 9 feet below the water surface (elevation 49.75)[2] at the deep position and 3 feet below the water surface (elevation 55.75) at the shallow position (fig. 5). Water depth in the area immediately downstream from the orifices was 19 feet.

Hydraulics.--Regulated water elevations (fig. 1) provided constant hydraulic conditions during the tests. Water levels in the transportation channels were maintained 1 foot higher than the level of the introductory pool, providing a 1-foot head on the orifices. This head produced a calculated flow of 49 c.f.s. and an average velocity of about 8 feet per second through each orifice. Flows equal to the orifice discharge were introduced at the head of each transportation channel; about 16.5 c.f.s. passed over the exist weir at the head of the channel, and the remaining flow entered through a submerged, screened port at the base of the exit weir.

Flows from shallow orifices caused a turbulence on the surface of the introductory pool (fig. 6A), whereas flows from deep orifices caused little or no surface turbulence (fig. 6B).

[2] All elevations are designated as feet above mean sea level.

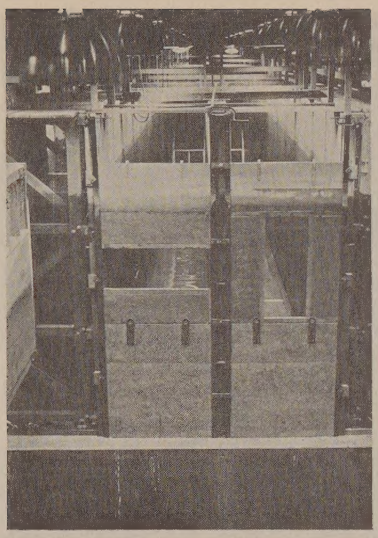


Figure 2.--Test area, drained to show horizontal (left) and vertical (right) orifices at the shallow setting. Centerline of each orifice is 3 feet below water surface. Structures on each side of orifice panels are screened to prevent entry of fish. Introductory pool is in foreground.

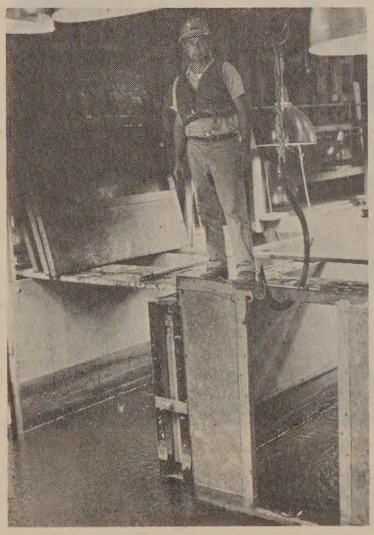


Figure 3.--Removing panel from guide slots to change position of orifice.

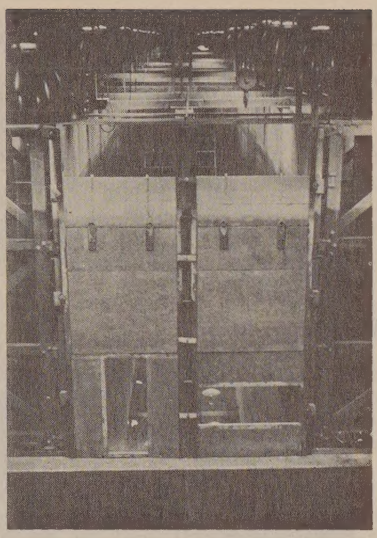


Figure 4.--Vertical and horizontal orifices at deep setting (centerline of each orifice is 9 feet below water surface).

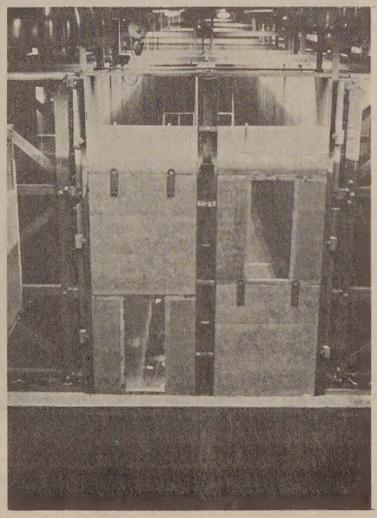
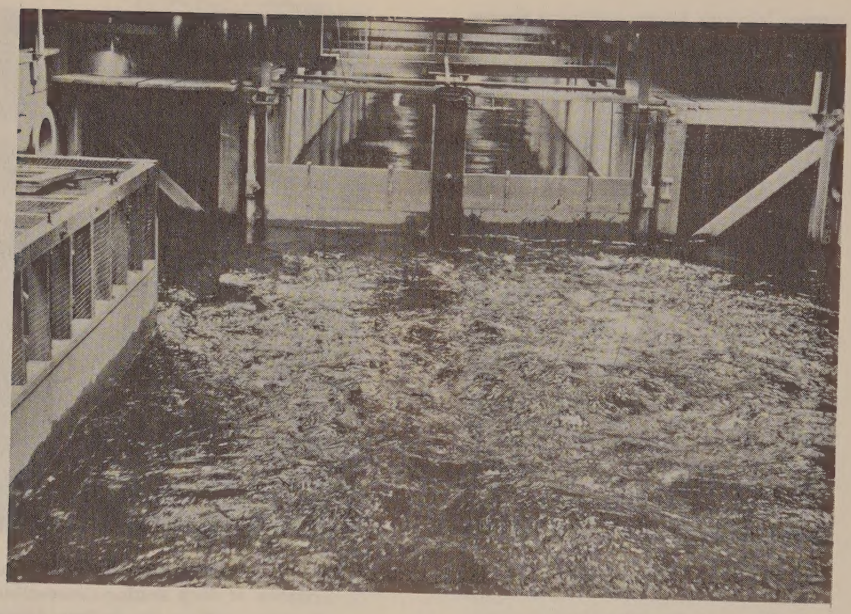


Figure 5.--Test condition for comparing responses of salmon to vertical orifices at deep (left) and shallow (right) settings.

(A)



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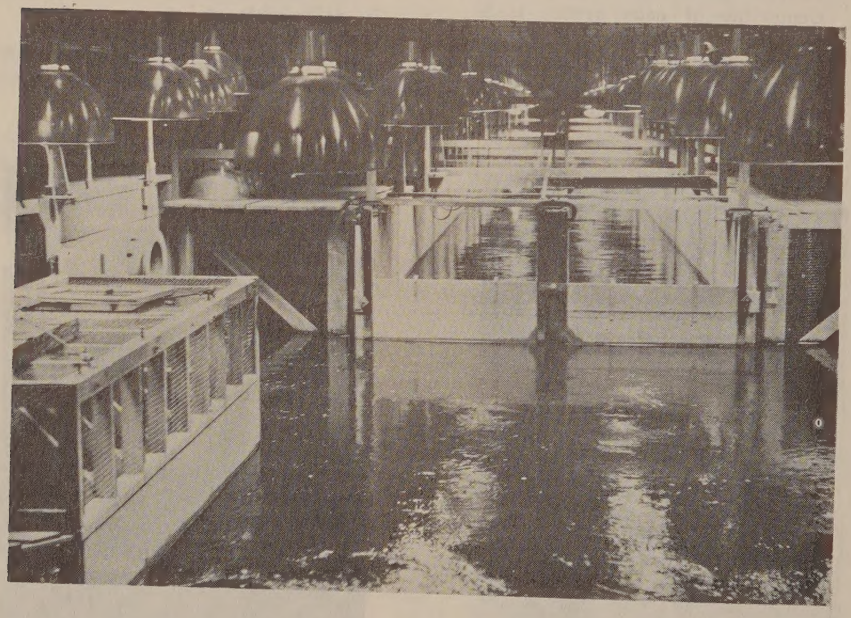

Figure 6.--Introductory pool (foreground) during discharge from shallow (A) and deep (B) orifices. Salmon were released from structure in left foreground.

Test Procedure

Test fish entered the laboratory from the fishway and were released into the introductory pool after an observer had determined the size and species of each fish. Fish were released as rapidly as they became available; thus, several fish may have been in the introductory area at the same time.

After passing through one of the orifices, test fish proceeded upstream through the transportation channel and crossed the exit weir. We recorded the response to an orifice

condition on the basis of numbers of fish of each species leaving the respective channels (fig. 7).

Figure 7.--Recording passage of fish at upstream end of transportation channels. Counts of fish leaving each channel provided a record of the response of these fish to the position and depth of the orifices at the entrance to the channels.

Experimental Design

The experiment was divided into the following four test conditions to examine the response of salmonids to orifice alignment and depth: (1) a horizontal and a vertical orifice, both 9 feet below the water surface; (2) a horizontal and a vertical orifice, both 3 feet below the surface; (3) two horizontal orifices, one 3 feet and one 9 feet below the surface; and (4) two vertical orifices, one 3 feet and one 9 feet below the surface. Test conditions 1 and 2 constituted one block, and test conditions 3 and 4 constituted another block. We randomized test conditions within blocks and ran blocks alternately for three or four replications.

Because of the possibility of more fish entering one channel than the other, regardless of the position or depth of the orifice, the orifices were changed from one channel to the other halfway through each test period. Each test period lasted 2 days because it was impractical, for both biological and mechanical reasons, to modify a test condition at intervals shorter than 1 day. We assigned orifices to the north and south channels randomly on the first day of each 2-day period.

This design requires the assumption that approach patterns remain similar on both days for a 2-day test period. In other words, if a majority of fish approach the test panel from the right side on the first day, a similar majority is assumed to do so the next day. Accepting this assumption, we computed the basic response measurements as follows:

1. The percentage of fish entering each orifice was calculated by day.
2. The daily percentages of fish entering a given orifice in each 2-day period (1 day in the south and the other in the north channel) were averaged to yield the measurement of basic response for that orifice.

We evaluated the response to orifices separately for each test condition. Averages of the percentage of fish entering each of two orifices being compared during a 2-day test period totaled 100 percent. Therefore, unequal use of the orifices was shown by the departure of the averages from 50 percent. Only average percentages from one of two orifices being compared were used in the evaluation. Since average percentages were replicated for each test condition, we applied t-tests to examine departure of their means from 50 percent. Arcsin transformations (Snedecor, 1957) of the average percentages were used to compute t-values.

RESPONSE OF SALMONIDS TO ORIFICE CONDITIONS

The analyses of our experiments, including four test conditions of orifice settings and observations on the lateral orientation of fish in the experimental system, are discussed in the following passages:

Test Condition 1--Deep horizontal orifice vs. deep vertical orifice

Significantly more than 50 percent of the chinook salmon and steel-head trout entered the vertical orifice (table 1). The percentage of coho salmon passing through the vertical orifice did not differ significantly from 50 percent.

Table 1.--Average percentages[1] of salmonids entering orifices in test condition 1--deep horizontal orifice vs. deep vertical orifice

[Asterisk, significant at 95-percent level; NS, not significant; mean percentages with neither designation not tested]

Replicate	Chinook salmon		Steelhead trout		Coho salmon	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Number	Percent	Percent	Percent	Percent	Percent	Percent
1 . . .	32.6	67.4	43.0	57.0	32.2	67.8
2 . . .	26.3	73.7	29.4	70.6	48.4	51.6
3 . . .	31.2	68.8	36.0	64.0	45.9	54.1
4 . . .	32.0	68.0	41.1	58.9	----	----
Mean. . .	30.6	69.4*	37.4	62.6*	42.1	57.9^{NS}
Total number of fish .	807		2,737		202	

[1] Direct observations during a basic time unit of 2 days were combined to form a response measurement called "average percentage" (see text for details).

Test Condition 2--Shallow horizontal orifice vs. shallow vertical orifice

None of the three mean percentages tested for chinook salmon, steelhead trout, and coho salmon differed significantly from 50 percent (table 2). Chinook salmon and steelhead trout demonstrated a trend toward use of the vertical orifice in three of the four replicates. In the exception (second replicate), this entrance pattern was reversed, and slightly more fish of both species entered the horizontal orifice. This reversal contributed appreciably to the nonsignificance of the mean percentages. Only two replicates were run with coho salmon. Although more fish passed through the vertical orifice than the horizontal orifice the difference was not significant.

Table 2.--Average percentages[1] of salmonids entering orifices in test condition 2--shallow horizontal orifice vs. shallow vertical orifice

[Asterisk, significant at 95-percent level; NS, not significant; mean percentages with neither designation not tested]

Replicate	Chinook salmon		Steelhead trout		Coho salmon	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Number	Percent	Percent	Percent	Percent	Percent	Percent
1 . . .	21.2	78.8	48.5	51.5	44.0	56.0
2 . . .	52.2	47.8	58.0	42.0	47.5	52.5
3 . . .	25.0	75.0	40.8	59.2	----	----
4 . . .	32.4	67.6	38.4	61.6	----	----
Mean . . .	32.7	67.3^{NS}	46.4	53.6^{NS}	45.8	54.2^{NS}
Total number of fish .	692		2,065		201	

[1] Direct observations during a basic time unit of 2 days were combined to form a response measurement called "average percentage" (see text for details).

Test Condition 3--Shallow horizontal orifice vs. deep horizontal orifice

Significantly more than 50 percent of the chinook salmon and steelhead trout entered the shallow horizontal orifice (table 3). Although more coho salmon entered the shallow than the deep orifice, the two replicates totaling 136 fish failed to show significant departures from 50 percent.

Test Condition 4--Shallow Vertical Orifice vs. Deep Vertical Orifice

None of the mean percentages for chinook salmon, steelhead trout, and coho salmon departed significantly from 50 percent (table 4). Although the trend for chinook salmon was toward the shallow orifice in all replicates, the strength of the trend differed widely among replicates. The majority of steelhead trout in the first two replicates tended toward the shallow depth. In the third replicate, however, steelhead were almost equally distributed between the two depths. Coho salmon demonstrated a trend toward the 9-foot depth.

Table 3.--Average percentages[1] of salmonids entering orifices in test condition 3--shallow horizontal orifice vs. deep horizontal orifice

[Asterisk, significant at 95-percent level; NS, not significant; mean percentages with neither designation not tested]

Replicate	Chinook salmon		Steelhead trout		Coho salmon	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
Number	Percent	Percent	Percent	Percent	Percent	Percent
1 . . .	78.8	21.2	69.2	30.8	63.9	36.1
2 . . .	84.2	15.8	66.6	33.4	59.8	40.2
3 . . .	72.7	27.3	73.2	26.8	----	----
Mean . . .	78.6*	21.4	69.7*	30.3	61.8^{NS}	38.2
Total number of fish .	720		2,131		136	

[1] Direct observations during a basic time unit of 2 days were combined to form a response measurement called "average percentage" (see text for details).

Table 4.--Average percentages[1] of salmonids entering orifices in test condition 4--shallow vertical orifice vs. deep vertical orifice

[Asterisk, significant at 95-percent level; NS, not significant; mean percentages with neither designation not tested]

Replicate	Chinook salmon		Steelhead trout		Coho salmon	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
Number	Percent	Percent	Percent	Percent	Percent	Percent
1 . . .	63.0	37.0	55.9	44.1	46.6	53.4
2 . . .	59.2	40.8	55.7	44.3	37.5	62.5
3 . . .	52.4	47.6	49.2	50.8	----	----
Mean . . .	58.2^{NS}	41.8	53.6^{NS}	46.4	42.0^{NS}	58.0
Total number of fish .	1,171		2,589		248	

[1] Direct observations during a basic time unit of 2 days were combined to form a response measurement called "average percentage" (see text for details).

Lateral Orientation of Fish in the Experimental System

In all replicates for all species except one (test 2, replicate 2) for steelhead trout, the percentage of salmonids entering any given orifice was greater when that orifice was on the south side of the introductory pool than when it was on the north. Table 5 shows remainders obtained by subtacting the percentage of salmonids entering a given orifice on the north from the percentage of those entering the same orifice where it was on the south side during each 2-day test period. Means of the remainders for each species were significantly greater (95-percent level) than zero (t-tests). Bias toward the south side of the system reduced the number of measurements by half because it required

Table 5.--Remainders obtained by subtracting the percentage of salmonids entering a given orifice when it was on the north side of the experimental system from the percentage of those entering the same orifice when it was on the south during each test period

[Asterisk, denotes a mean difference than was significantly greater (95 percent level) than zero]

Test	Replicate	Chinook salmon	Steelhead trout	Coho salmon
Condition	Number	Percent	Percent	Percent
1 . . .	1	59.5	29.8	----
	2	9.2	10.5	35.7
	3	9.1	14.7	3.3
	4	31.0	30.0	57.6
2 . . .	1	16.4	60.6	----
	2	4.4	[1] -0.4	----
	3	21.0	30.1	30.8
	4	36.9	25.3	30.8
3 . . .	1	20.7	11.0	----
	2	2.8	26.8	27.8
	3	25.8	25.3	45.6
4 . . .	1	12.8	24.6	----
	2	30.5	30.0	18.1
	3	31.1	38.4	46.6
Mean		22.23*	24.05*	32.92*

[1] All of the other values shown are positive.

use of a full 2-day test period for each set of conditions compared.

Treatment of the data was based on our assumption that position of the laboratory equipment caused more fish to enter the south orifice than the north. This assumption may be erroneous. If so, more accurate percentages of fish entering a given orifice would be obtained if the fish that entered on the south side--regardless of the orifice presented there--were removed entirely from consideration. The results of tests shown in tables 1-4 are changed by this treatment only for coho salmon under test condition 3 (shallow horizontal vs. deep horizontal). The trend toward higher use of the shallow horizontal orifice by coho salmon shown in the first treatment is changed to a significantly greater use of that orifice by the second treatment.

INTERPRETATION

Since volume and velocity of attraction flows were all equal, our analysis of the response of fish under the different conditions considers only the position of the orifices. The four test conditions comprise four experiments on different aspects of orifice use. Each experiment can be examined individually by statistical techniques, but results of the different experiments cannot be combined and examined by the same techniques for a common analysis. Rather, the general pattern of use must be deduced by inspection of the results of the four experiments. We feel that the following deductions of what might have happened in the introductory area can be useful in developing new hypotheses for future testing.

Taking into consideration all of the material available to us in the tests with chinook salmon and steelhead trout, we have developed the following rationale: A substantial number of migrating chinook salmon and steelhead trout evidently approached the test panel in the introductory pool at depths between 3 and 9 feet. If an orifice was present in their plane of travel, they entered at that level. This is indicated because it was not possible to demonstrate a significant difference between use of shallow and deep vertical orifices, but a significant difference was found between shallow and deep horizontal orifices. If an orifice was not present in their plane of travel, migrants presumably searched upward and laterally beyond the first passable opening encountered. This is indicated by greater use of the horizontal orifice centered at 3 feet than the one centered at 9 feet, and for the inconsistency between replicates when vertical and horizontal orifices were centered at 3 feet. If a downward search was required, its lateral aspect presumably terminated at the first passable opening encountered. This is indicated by the greater use of the vertical orifice when vertical and horizontal orifices were centered at 9 feet.

The laboratory facilities provided a reasonably deep approach area (19 feet) but the depth range of the orifices was limited to 9 feet because of the existing sill of the transportation channel. Deeper submergence of orifices may have produced more clear-cut responses, particularly in comparisons of the response to vertical orifices at shallow versus deep positions.

In the application of these results to a prototype, the effect of competing turbine discharges must be considered. Because the turbines discharge at depths beneath existing collection-channel ports, it is possible that competing attraction flows (i.e., turbine vs. collection-channel discharges) might influence the vertical distribution of fish as they approach a powerhouse collection channel. This situation could produce results somewhat different from those noted in the laboratory, where the effect of the turbine discharge was not a factor.

We must emphasize that we studied salmonids that were actively moving upstream, and that all orifices, regardless of shape or location, were entered by at least some members of every species observed on any day.

SUMMARY AND CONCLUSIONS

Migrating adult salmonids were presented with an alternative of entering one of two orifices. Each orifice measured 2 by 5 feet and was aligned either horizontally or vertically at shallow or deep settings (3 or 9 feet measured from the centerline of the orifice to the water surface of the introductory area). A 1-foot head was maintained on the orifices. Orifice settings were changed daily and offered the test fish entry to: (1) vertical and horizontal orifices set deep, (2) vertical and horizontal orifices set shallow, (3) shallow and deep horizontal orifices, and (4) shallow and deep vertical orifices.

Unequal use was demonstrated when both vertical and horizontal orifices were centered 9 feet from the surface, and when horizontal orifices were centered at 3 and 9 feet. When both orifices were at 9 feet, more salmonids used the vertical orifice which, although centered at the same depth as the horizontal one, extended farther above and below the mean depth than the horizontal orifice. When horizontal orifices were centered at 3 and 9 feet, more salmonids used the shallow orifice than the deep one.

Unequal use was not demonstrated when both vertical and horizontal orifices were centered 3 feet below the surface. When vertical orifices were placed at both depths, percentages of fish entering the shallow orifice were not uniformly greater than those entering the deep orifice.

In conclusion, the vertical orifice generally is more suitable than the horizontal orifice and the shallow orifice is more suitable than the deep orifice for chinook salmon, steelhead trout, and coho salmon where centerline submergence is 3 and 9 feet.

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